Group-based Ad-hoc Network for Multimedia Communications

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Abstract-**This paper is concerned with evaluating ad-hoc networks for group-oriented tactical operations. For such operations, a cellular-based ad-hoc network architecture has been constructed for real-time multimedia communications. To assess the suitability of this network, its performance has been compared with conventional peer-to-peer ad-hoc network architectures under various test scenarios using IEEE 802.11 WLAN technology. We have shown that the cellular network, which operates in two modes: infrastructure for intracell and ad-hoc for intercell communications, is more suitable for group-based tactical missions.**

Index-terms-Ad-hoc networks, MANET, IEEE 802.11, WLAN, multimedia, video, cellular

I. Introduction

Recent advances in Wireless LAN (WLAN) technologies, such as the IEEE 802.11 standard [1], have provided new opportunities to develop an experimental platform to design and assess ad-hoc networks for transmission of multimedia information in realistic environments [2], [3]. This standard defines the carrier sense multiple access protocol combined with collision avoidance (CSMA/CA) [1]. The protocol supports WLAN in two different modes: infrastructure and ad-hoc.

In the infrastructure mode, mobile nodes communicate with each other via an access point (AP). For a peer-to-peer multihop ad-hoc operation, the standard specifies a basic access protocol called Distributed Coordination Function (DCF). In addition to the DCF, the infrastructure mode can support another access protocol known as the Point Coordination Function (PCF) [1], which is suitable for delay sensitive services. Performance trade-offs between centralized and distributed schemes have been studied by several researchers [4]-[7]. Based on these studies, a dual mode operation in the form of a hybrid multihop cellular network can be perceived as a way towards the next evolutionary step in wireless technology. However, based on the IEEE 80.11b standard, we have considered a multihop cellular network configuration, whose performance will be evaluated for real-time signals. Thus, we examine the throughput performance of this IEEE 802.11-based hybrid network as compared with the peer-to-peer ad-hoc network.

The paper is organized by firstly providing a brief overview of cellular ad-hoc networks. We then present test scenarios that are based on two network topologies to compare the relative performance of both networks for video signals. Finally, based on our experimental testbed, we show that this network, with its inherent cellular structure, is suitable for group-oriented tactical operations.

II. Cellular Multihop Network

Figure 1 shows the network configuration, which consists of two types of mobile nodes: Mobile Base Node (MBN) and Mobile Node (MN). The MBN behaves like a moving base station and thus, communicates with its mobile nodes in an infrastructure mode. This would require deploying a WLAN access point (AP) in order to construct a mobile MBN. Since AP cannot operate in an ad-hoc mode for communicating with other MBN's, a simple architecture has been used to allow one AP to communicate with other APs wirelessly and in an ad-hoc mode [8]. In this architecture, packets received by an AP are routed via a LAN interface (using PDA or laptop), to a wireless network interface card.

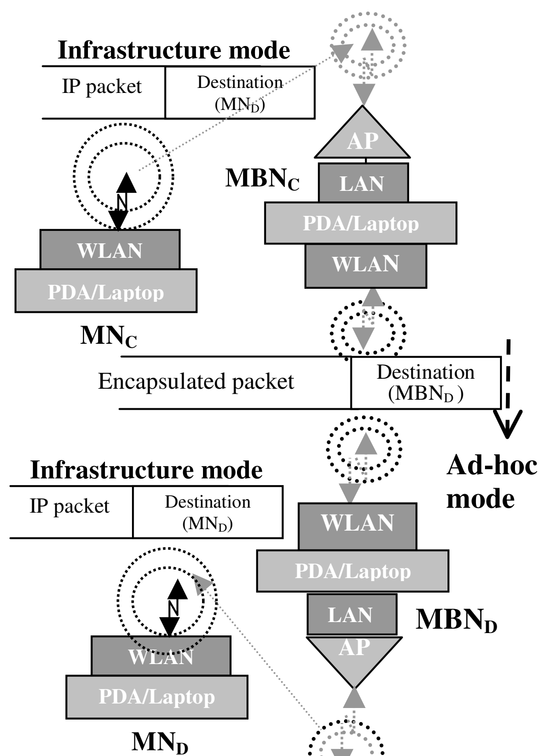

Fig. 1. Cellular-based mobile multihop ad-hoc network using a tunneling technique.

Consequently with this arrangement, an MBN can be formed, which can operate in both infrastructure and ad-hoc modes. In addition, an MN, which consists of only a wireless network interface card and a PDA (or a laptop), can function solely in the infrastructure mode.

As shown in Fig.1, communication between mobile nodes in different cells is accomplished through their respective MBN's in a similar fashion as conventional cellular networks. However, a distinct difference in this case is that MBN's themselves can also function as active mobile nodes (e.g., group leaders). These nodes under group-oriented operations, are capable of initiating communications not only with their mobile nodes, but also with other MBN's and/or their associated mobile nodes. As shown in Fig.1, if packets are initiated at an MN (i.e., MN_C in Fig. 1) but destined to another MN attached to a different cell (MN_D), they have to undergo a tunneling process. In other words, they are first encapsulated at the source MBN (MBN_C in Fig. 1) and then de-capsulated at the destination MBN (MBN_D) before being forwarded to their final destination mobile node (MN_D).

Naturally, the tunneling process won't be necessary if IP packets are initiated and terminated at MBN's. Fig. 2 shows an example of how different nodes communicate with each other in a three-cell network structure.

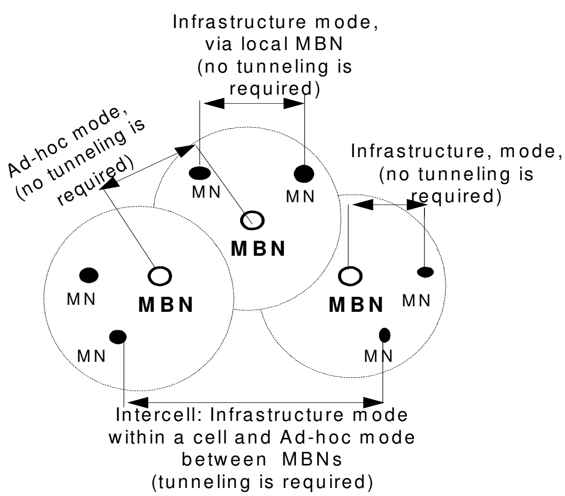

Fig. 2. Multihop Cellular Network for group based operations

A major factor which can affect the throughput performance of this network is the co-channel interference amongst neighboring cells. Note that the IEEE 802.11 standard defines two types of RF based LANs for the physical layer; DSSS (Direct Sequence Spread Spectrum), and FHSS (Frequency Hopping Spread Spectrum).

In the DSSS case, the co-channel interference can be avoided only if non-overlapping channels are selected for each cell (i.e., 1, 6 and 11) [1]. Nevertheless, when the number of cells is more than two, the co-channel interference cannot be entirely eliminated as the third non-overlapping channel may have to be reserved for communication between MBN's which operate in ad-hoc mode. In addition, to extend the coverage area, a higher number of cells may have to be deployed and this may necessitate utilizing other overlapping channels. In this situation, the FHSS option can be considered to mitigate the effect of co-channel interference. However, the main disadvantage of FHSS is its lower data rate of 1 Mb/s. Bear in mind that FHSS also supports the 2 Mb/s rate but its link performance is relatively poor (due to the deficiencies of the 4-level GFSK modulation) compared with DSSS at the same data rate. However, as our objective is mainly to evaluate the cellular network performance compared with peer-to-peer ad-hoc network, the FHSS system has been used for the infrastructure (intracell) part and DSSS for communication in ad-hoc mode.

III. Network Performance Evaluations

In the following experiments, we compare the throughput performance of the mobile cellular ad-hoc network with conventional ad-hoc network systems. In our experimental testbed, we used 1Mbps IEEE 802.11 FHSS for the infrastructure mode and 2Mbps IEEE 802.11 DSSS for the ad-hoc mode. AODV ad-hoc routing protocol [9] has been used for communication between MBN's.

For fair comparison, we have defined two connection topologies, which will be the basis for assessing both networks under different scenarios. Each network consisted of nine mobile nodes where, in case of cellular networks, three of these nodes are MBNs and forms a three-cell network structure. Fig. 3 shows the connection topologies for a mobile cellular ad-hoc network, where each cell consists of a mobile base node (MBN) and two mobile nodes (MN's). The connection topologies for the peer-to-peer ad-hoc network are shown in Fig. 4. Note that in these figures, a link between a pair of nodes in the infrastructure mode is signified by a solid line whereas in the case of an ad-hoc mode, it is shown by a dotted line. In addition, a line with two sided arrows indicates a direct two-way (bi-directional) communication link.

In these experiments, we created communication pairs (source-destination pairs) to transport RTP/UDP/IP video packets in real-time. For both connection topologies, we have created three different types of scenarios to compare the two networks.

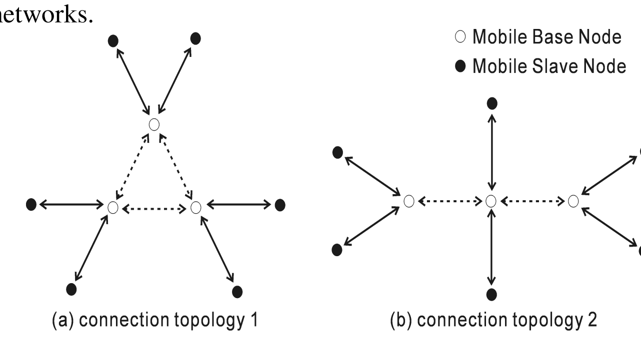

Fig 3. Network connection topologies for mobile cellular networks.

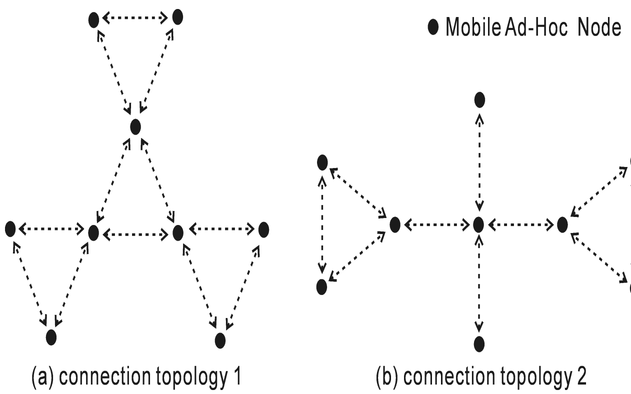

Fig. 4. Network connection topologies for mobile ad-hoc networks.

Fig. 5 illustrates the data flows in two topologies for the first scenario (scenario 1), where each topology is comprised of twelve (one-way) active simultaneous communication links. In this figure, an arrow indicates a flow of data packet stream from the source node to the destination node. In addition, each node in this figure corresponds to the node in the same locations shown in Fig. 3 and Fig. 4. Fig. 6 and Fig. 7 show the aggregate throughput performance for both networks using connection topologies 1 and 2, respectively. In these experiments, the source node in each communication pair sends RTP/UDP/IP packets with a 612-byte payload to the destination node at a constant bit rate. Note that in these figures, abscissa is the bit rate of each communication pair and ordinate is the total throughput of whole communication pairs. These results clearly show that the cellular network outperforms the conventional peer-to-peer ad-hoc network. This simply verifies that the cellular network, which utilizes a different channel, suffers less interference from other active nodes located in different cells (intercell-interference).

In our next set of experiments, we considered a different scenario (scenario 2), in which both topologies, including their data flows, are depicted in Fig. 8. Similarly, there were also twelve active simultaneous communication links where the source node sends 612-byte RTP/UDP/IP data packets to the destination node. As can be observed from Fig. 8a, the communication load in the cellular network consists of intercell pairs (i.e., MN-to-MN via MBN's) and MBN-to-MBN pairs.

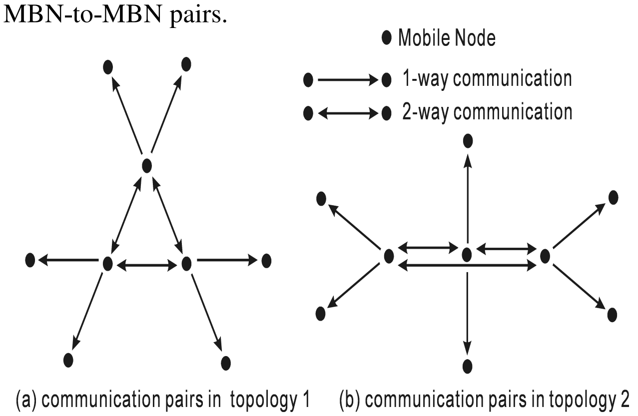

Fig. 5. Communication pairs for scenario 1.

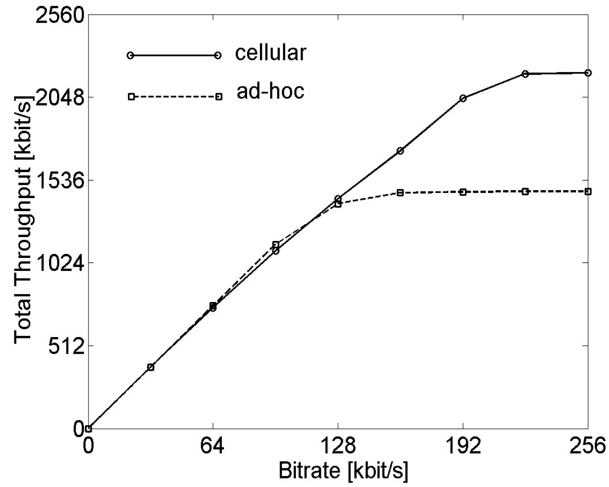

Fig. 6. Throughput performance for scenario 1 in topology 1.

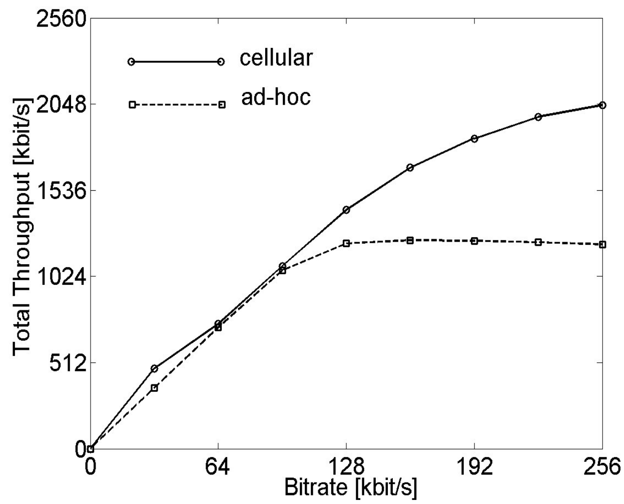

Fig. 7. Throughput performance for scenario 1 in topology 2.

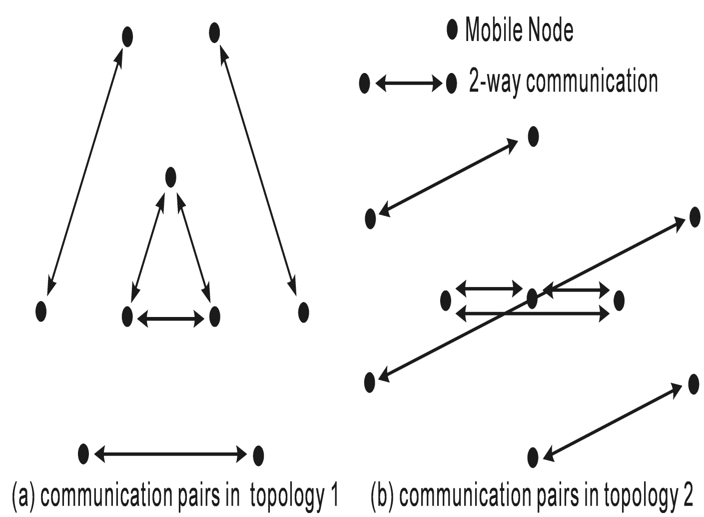

Fig. 8. Communication pairs for scenario 2.

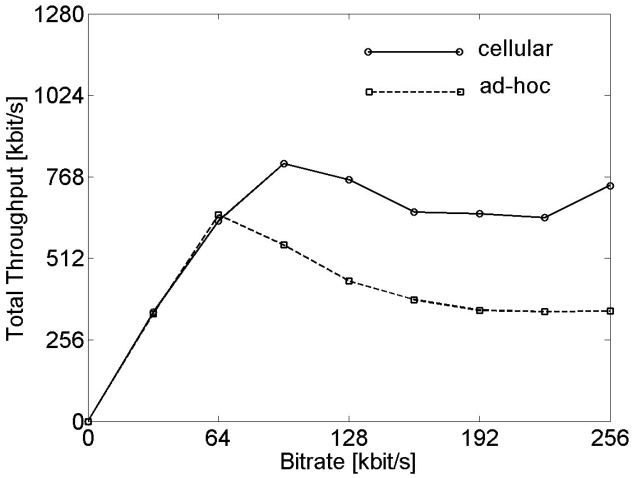

Fig. 9. Throughput performance for scenario 2 in topology 1.

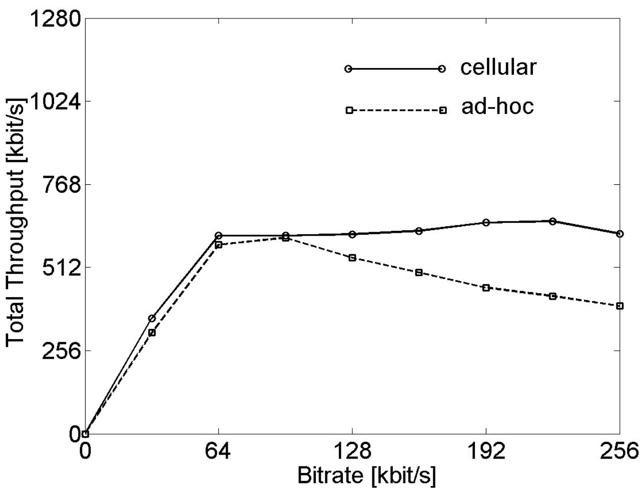

Fig. 10. Throughput performance for scenario 2 in topology 2.

The throughput results for scenario 2 are shown in Fig. 9 and Fig. 10 for topologies 1 and 2, respectively. These results also confirm a superior performance of the mobile cellular network over the peer-to-peer ad-hoc network. Another consideration, which is more noticeable in this scenario, is that the cellular system tends to undergo a smaller number of hops (e.g. intercell MN-to MN) than its peer-to-peer counterpart and this has been an important contributing factor in reducing the co-channel interference (see Fig. 3 and Fig. 4).

In our final set of experiments, the objective was to create a scenario which is not favorable for a group-oriented networking operation. For instance, MBN's no longer function as active nodes as they behave like a conventional base station (except they are not supported by a wired backbone network). The data flows for this scenario are depicted in Fig. 11. To examine the effect of traffic load in the infrastructure mode, we increased the number of intracell communication pairs. It should be noted that the amount of real-time traffic, in this case, includes simultaneous transmissions from the source node (MN) to the AP (MBN), and from AP to the destination node (MN).

We should point out that in our experimental testbed implemented for the cellular network, we had to use 1 Mb/s FHSS (instead of 2 Mb/s) WLAN for the infrastructure part of the network. This has unfairly constrained the bandwidth availability for intracell communications. Having this in mind, the results of these experiments are shown in Fig. 12 and Fig. 13, which correspond to the network topologies 1 and 2, respectively. As can be observed from these figures, the multihop cellular network in this case does no longer maintain its superiority over the peer-to-peer ad-hoc. One factor affecting the cellular network performance is that in both topologies, MBN's are no longer involved in initiating communications. Indeed, MBN's operate more like a mobile base station and therefore the network lacks the necessary feature for group-based operations.

Another unfavorable factor is the increased intracell traffic, which tends to reduce the aggregate traffic in the network. Nevertheless, we should emphasize once again that in these experiments 1 Mb/s FHSS WLAN had to be used and this has further limited the cellular network throughput performance in the infrastructure mode. Finally, the most important attribute of the cellular network is the MBN's ability to operate as an active node communicating not only with its mobile nodes but also with other nodes wirelessly. It is based on this important property that the network is suitable for group-based applications.

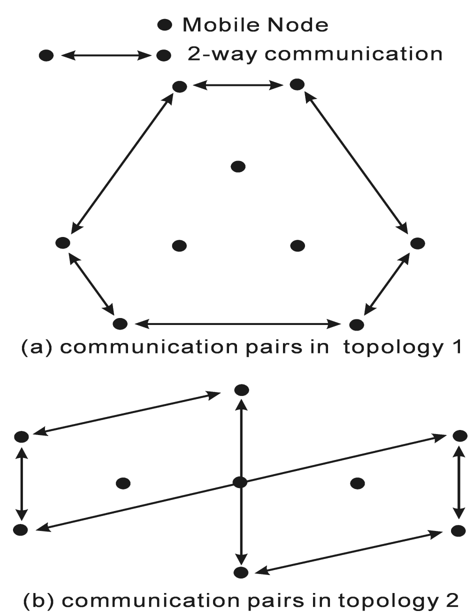

Fig. 11. Communication pairs for scenario 3.

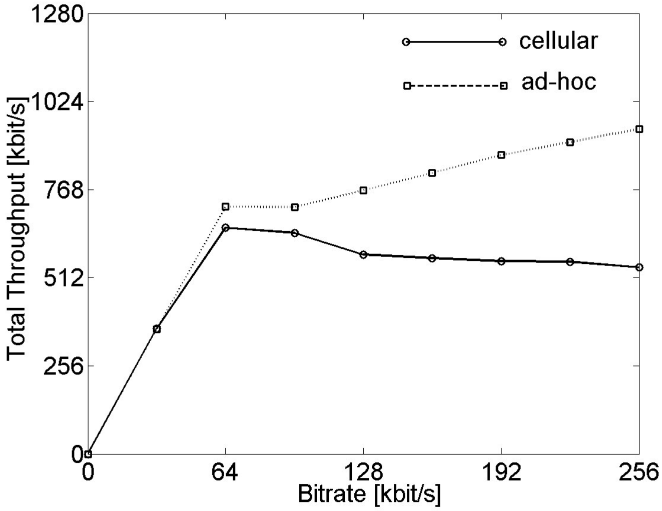

Fig. 12. Throughput performance for scenario 3 in topology 1.

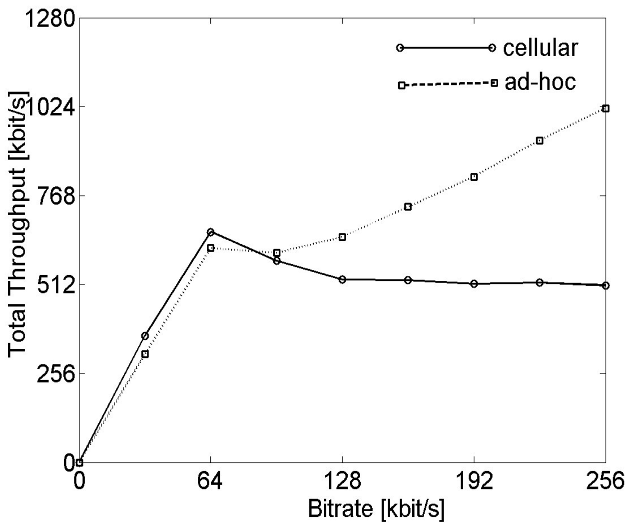

Fig. 13. Throughput performance for scenario 3 in topology 2.

IV. CONCLUSION

In this paper, we considered a cellular multihop ad-hoc network for real-time communications. This network operates in infrastructure mode for intracell and ad-hoc mode for intercell communications. It has been compared with a peer-to-peer ad-hoc network in terms of aggregate throughput performance. Due to differing network structures, these assessments were carried out under various scenarios and connection topologies. The outcome of these assessments verifies the fact that this network is highly suitable for group-oriented operations. However, in cases where the network is structured to function more like a conventional cellular network (without a wired backbone), it loses its performance superiority over peer-to-peer networks. This is mainly due to the communication bottleneck caused by excessive intracell activities amongst the mobile nodes.

REFFERENCES

[1] ANSI/IEEE Std 802.11 1999 Edition, Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Institute of Electrical and Electronic Engineers, Aug. 1999.

[2] A. Ganz, A. Phonphoem, N. Llopis, I. Kim, K. Wongthavarawat, and Z. Ganz, "Converged voice, video and data wired-wireless LANs testbed," Conference Proceedings, IEEE MILCOM, Vol. 2, pp. 1297 –1301, Oct/Nov 1999.

[3] J. Feigin and K. Pahlavan, "Measurement of characteristics of voice over IP in a wireless LAN environment," IEEE International Workshop on Mobile Multimedia Communications, pp.236-240. Nov. 1999.

[4] Y.-D. Lin and Y.-C. Hsu, "Multihop Cellular: A New Architecture for Wireless Communications. In Proceedings of INFOCOM. IEEE, 2000.

[5] O. C. Mantel, N. Scully, and A. Mawira. "Radio Aspects of Hybrid Wireless Ad Hoc Networks, Proceedings of VTC. IEEE, 2001.

[6] H.-Y. Hsieh and R. Sivakumar, Towards a Hybrid Network Model for Wireless Packet Data Networks, Proceedings of ISCC. IEEE, 2002.

[7] N. B. Salem, L. Buttyan, J.-P. Hubaux, M. Jakobsson, "A Charging and Rewarding Scheme for Packet Forwarding in Multi-hop Cellular Networks, MobiHoc '03, pp. 13-24, June 2003.

[8] H. Gharavi and K. Ban, "Multihop Sensor Network Design for Wideband Communications," THE PROCEEDINGS OF THE IEEE, vol. 91, NO. 8, August 2003, pp. 1221-1234.

[9] C. E. Perkins, E.M. Royer, S.R. Das, "Ad Hoc On Demand Distance Vector (AODV) Routing, " Internet Engineering Task Force, RFC 3561, July 2003.